Affidavit Regarding Benzene Exposures of Mr. Ben Brown

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I am Adjunct Professor of Environmental Health Sciences, and Director of the Industrial Hygiene Graduate Program, at the School of Public Health, University of California, Berkeley. I have been a practicing industrial hygienist for 32 years and a Certified Industrial Hygienist (Diploma Number 3462) for 22 years. Past jobs include working as an industrial hygiene inspector for the federal Occupational Safety and Health Administration (OSHA), as an industrial hygienist for a labor union, as an industrial hygienist for a chemical company, and as an industrial hygienist for the States of California and Wisconsin. I am a Fellow of the American Industrial Hygiene Association (AIHA) and the 2001 recipient of the AIHA Edward J. Baier Technical Achievement Award. I am the primary author or coauthor on 55 peer-reviewed publications and eight book chapters, of which the majority pertain to exposure assessment issues. I am an Editorial Board member of the Journal of Occupational and Environmental Hygiene, a joint publication of the AIHA and the American Conference of Governmental Industrial Hygienists (ACGIH). The AIHA and ACGIH are the two leading U.S. professional organizations for industrial hygienists.

My area of specialization is exposure assessment, which includes the mathematical modeling of exposure. At the University of California, I teach two graduate courses titled "Exposure Assessment and Control I" and "Exposure Assessment and Control II". Assessing the dermal absorption of benzene is discussed in my course presentations. My CV is attached hereto.

I was asked to consider the benzene exposures experienced by Mr. Ben Brown during his work on offshore oil and gas platforms in the years 1968-1992. After reviewing materials provided by Mr. Singelstad, and speaking with Mr. Brown on the phone on January 4, 2009, I prepared a preliminary report dated January 5, 2009. Subsequent to that report, I received transcripts of the deposition testimony of Mr. Brown and Mr. Joe Tallo, five recorded witness statements, and other materials from Mr. Singelstad. This new information has caused me to modify some opinions I offered in my January 4, 2009, report. Because I understand there will be additional materials to consider, I offer a preliminary analysis of some of Mr. Brown's benzene exposures. I offer these opinions with a reasonable degree of scientific certainty. I leave open the possibility that I may revise my opinions based on additional information received.

My consulting rate for office-type work and travel is $280 per hour, and my fee for testimony at deposition and trial is $500 per hour.

GENERAL JOB DESCRIPTION

My understanding is that Mr. Brown was first hired as laborer with Shell Oil in 1968, became a maintenance man in 1969, and was a lease operator managing oil and gas production from late September 1974 through about 1986. The job duties of a laborer were similar to those of a maintenance man. After 1986 until August 1992, Mr. Brown worked as a senior lease operator. In the latter position, most of his work was done on shore at Shell East Bay facilities, although he

Exhibit F

continued doing some work offshore on the production platforms. He said his offshore work in all these positions was "hands on". Mr. Brown worked a schedule of 7-days-on/7-days-off, and worked 12 hours a day. In the period 1968 to 1986, he commuted daily from the Shell East Bay shore-side facility out to the platforms and returned to the base in the evening to sleep in barracks.

During the period 1968 to late September 1974, Mr. Brown worked mostly in Block 24, which was an area several miles off the mouth of the Mississippi River at South Pass in southern Louisiana. Block 24 was part of the Shell East Bay oil field. In Block 24, there were 300 to 350 wells in about 100 satellite platforms or "well jackets". Each well jacket had one to four wells. In Block 24, there were four production platforms and one free water knockout (FWKO) platform. All the crude oil flowing from the wells went into low-pressure, vertical separator tanks on the production platforms and then to FWKO platform. The crude oil mixture extracted by the wells from under the sea bed contained 60% to 70% water. Mr. Brown said the crude oil mixture was "very pourable and watery". The separator tanks received the watery crude oil from the surrounding wells via pipelines, and separated the material into three parts – gas on top, oil in the middle, and water on the bottom. The oil, gas and water had to be separated before the crude oil went into storage tanks for subsequent pumping to shore.

As a laborer, maintenance man and lease operator, Mr. Brown performed a variety of tasks that caused him to have inhalation and/or dermal exposure to benzene. I have sufficient information for certain tasks to permit my offering preliminary exposure estimates. For certain other tasks with the potential for causing substantial benzene exposure with regard to short-term exposure intensity and/or cumulative exposure, I briefly describe available details. However, based on just two processes for which I can offer preliminary exposure estimates – (i) cutting paraffin and cleaning the associated equipment, and (ii) applying Black Magic paint/tar to pipe – Mr. Brown's estimated cumulative benzene exposure ranges from 2.41 ppm-year at the low end to 5.82 ppm-year at the high end. However, it is certain that Mr. Brown experienced additional benzene exposures as a laborer/maintenance man and as a lease operator.

PARAFFIN CUTTING

Mr. Brown did paraffin cutting work full-time for 1½ to 2 years (page 51, Brown deposition, Volume I; page 20, Brown deposition, Volume III). My understanding is that he did this work toward the end of his classification as a maintenance man (page 53, Brown deposition, Volume I). Mr. Brown performed this work by operating a self-propelled, self-elevating barge. He was assisted by a laborer deckhand. Mr. Brown did paraffin cutting at all the well heads on the satellite well platforms in Block 24. For about half of the well heads, he pumped solvent into the well to assist in removing the paraffin. Paraffin cutting could take one to two days to complete at a single satellite well platform. After completing the work at one satellite well platform, he moved the barge to another satellite well location and repeated the operation.

The operation involved cutting tools that ran down into the well pipe. The barge crane lifted a tubular lubricator, the bottom of which was attached to the well head. A winch on the barge deck let out and reeled back a wire line equipped with cutting tools at its end. The wire line was lowered down through the lubricator and into the well piping. The cutting tool had a set of knives

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that removed the paraffin adhering to the interior pipe walls. Paraffin cutting often employed a solvent that was pumped from a 55-gallon barrel on the barge deck into the well piping. The solvent drum was opened and a pipe was introduced through the opening. A pump moved solvent from the drum, through a hose up to the top of lubricator, and down through the lubricator into the well pipe. The solvent dissolved the paraffin and improved the cutting action of the knives.

Mr. Brown said that during paraffin cutting, he spent about half his time close to the well head and controlled the wire by operating an engine that lowered and raised the wire. He said that while controlling the wire, he held a control lever with his right hand and kept his left hand on the wire. He said he wore cloth gloves that were supplied by Shell, and that the glove on his left hand was saturated with solvent while he controlled the wire. He said that the skin of his left hand stayed cracked all the time due to the solvent.

Mr. Brown said that the odor of the solvent was strong during the entire cutting operation. He said the odor came from the open solvent drum, the pump, the lubricator and the well head. He said this direct solvent exposure occurred every day at work during this 1½ to 2 year period.

Identity of the Solvent: Mr. Brown said he did not recall the labeling on the solvent drums. In my January 5,2009, report, I assumed that Mr. Brown worked with "reformate" from the Shell refineries. Shell Operations Instruction Letter No. 4.08, dated December 1988, "Procedure for Clearing Plugged or Partially Plugged lines" (SHELL-BBROWN-004145-004149), refers to removing paraffin from obstructed or plugged well pipe with the use of solvents. The document states: "The solvents used, such as 'reformate', are quite volatile; careful consideration should be given to their safe handling ... ."

According to Mr. Joe Tallo, who was a Shell offshore maintenance foreman from the mid-1960's to 1976, the solvent used for paraffin cutting and all other cleaning tasks on boats and platforms was TS-28R (various pages, Tallo deposition, Volumes I and II). He said this code was marked on the top or side of the drum (page 21, Volume I). However, the statements of three former Shell employees (in addition to Mr. Brown) contradict Mr. Tallo's statement about the TS-28R marking. Mr. Lynn Simar said that the solvent was in second-hand 55-gallon drums with the word "Solvent" hand-written on the top of the drum (February 13,2009). Mr. Presley Davenport said that the solvent was in drums with the word "Solvent" hand-written in chalk on the top of the drums (February 3,2009). Mr. Billy Ray Peavey said there was no labeling on the drums of solvent that he used (February 23,2009). In addition, Mr. Mike Hester said that that the solvent was transferred into the drums from a large bulk tank on shore (March 12,2009). Mr. Jerry Daughdrill said the solvent that he recalled using "evaporated extremely fast" and "would dry your skin out and take all the oils out of your skin so fast" (March 10,2009). I note that Mr. Brown testified that the words "Sol" or "Solvent" were hand written on the drums, and that the drums bore no stenciling or paper labels (page 98, Brown deposition, Volume I; page 43, Brown deposition, Volume III).

According to a document titled Shell Chemical Hydrocarbon Solvents (East of Rockies), SC:99-75 (printed 10/75), TS-28R has a 50% evaporation time of 1570 seconds (26.17 minutes), a 100% evaporation time of 4930 seconds (82.17 minutes), and an initial boiling point of 315° F.

The latter solvent is clearly less volatile than "reformate". A Shell MSDS for "light reformate" (with a 10-20% benzene content) lists an initial boiling point (IBP) of 95° F. A Shell MSDS for "heavy catalytic reformed naphtha", or heavy reformate (with a 1-2% benzene content) lists an IBP of 194° F. I conclude that TS-28R does not correspond to a solvent that is "quite volatile ... such as reformate" per the paraffin cutting Operations Instruction Letter, and was not used in the paraffin cutting operation. According to the Shell SC:99-75 document, the Shell solvents with IBP's in the range of 95° to 194° F start with Shell Sol B (IBP = 137° F) and end with Shell Tolu-Sol 5 (IBP = 193° F). These two solvents have 100% evaporation times of, respectively, 2.92 minutes and 3.61 minutes, and are closer to Mr. Jerry Daughdrill's description of a solvent that "evaporated extremely fast" than TS-28R with a 100% evaporation time of 82.17 minutes. According to the Shell Deer Park "Solvents Handbook" dated February 1977, the benzene content of Shell Sol B was 0.74% by weight, and the benzene content of Shell Tolu-Sol 5 was 0.39% by weight. Therefore, I reasonably conclude that Mr. Brown used a Shell solvent with a benzene content in the range 0.39% to 0.74% by weight.

Dermal Exposure to Benzene: The mass of benzene dermally absorbed due to continuous skin contact with pure benzene is the product of the flux of pure benzene (mg/cm^2-hr), the surface area (SA, cm^2) of wetted skin, and the duration of contact (T, hr):

Eq. (1)   Dermally Absorbed Mass (mg) = (Flux, mg/cm^2-hr) × (SA, cm^2) × (T, hr)

As summarized by Kalnas and Teitelbaum (International Journal of Occupational and Environmental Health, Volume 6, pages 114-121, 2000), there is variability in the reported flux for the dermal absorption of benzene. Among several *in vitro* studies with human epidermal skin and using pure (neat) benzene, the flux ranged from 0.25 mg/cm^2-hr to 1.85 mg/cm^2-hr. An *in vivo* study with human volunteers yielded a flux of 0.4 mg/cm^2-hr (Hanke, et al, Medycyna Pracy, Volume 12, pages 413-426, 1961; reprinted in International Journal of Occupational and Environmental Health, Volume 6, pages 104-113, 2000). A recent paper reported results of an *in vivo* study with human volunteers conducted prior to 1993 (Modjtahedi and Maibach, Food and Chemical Toxicology, Volume 46, pages 1171-1174, 2008). A 0.1 mL aliquot of pure benzene was applied to 4 square inches (25.8 cm^2) on either the forearm or palm and allowed to evaporate. An average of 0.1% of the applied benzene mass was absorbed; although the percent absorbed was 0.13% for the palm and 0.07% for the forearm, these percents were not significantly different given the variability in the data. According to Dr. Maibach, the benzene visibly disappeared due to evaporation in less than 60 seconds (personal communication, 09/09/08). I observed that 0.1 mL of 2-butanone (vapor pressure of 78 mm Hg at 20 °C, similar to benzene's vapor pressure of 75 mm Hg at 20 °C) applied to less than 4 square inches of palmar skin disappeared in approximately 30 seconds. Assuming a disappearance time (due primarily to evaporation) of ½ minute for 0.1 mL benzene applied to 4 square inches of human skin, the estimated benzene flux in the Modjtahedi and Maibach study was 0.41 mg/cm^2-hr, or: [0.001 × (0.1 mL) × (880 mg/mL)] ÷ [(25.8 cm^2 × 0.00833 hr)] = 0.41 mg/cm^2-hr. This is essentially the same flux value reported by Hanke, et al.

It is unlikely that additional studies of benzene dermal uptake in human volunteers will be conducted due to the arguably unethical nature of such experiments (purposefully exposing a person to a known leukemia-causing chemical) and the advent of stricter oversight of human

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subject protection in research studies. The recent article by Nies and Korinth (Toxicology In Vitro, Volume 22, pages 275-277, 2008) comments on the unethical nature of a benzene dermal uptake study with human volunteers. In an introduction to the Year 2000 reprint of the Hanke study, Maibach and Teitelbaum wrote as follows: "This research, despite its careful design and precision of the method, could not be conducted today in most countries of the world. The use of human subjects, including the authors, in a study of skin absorption of a known carcinogen would not be allowed." I note that skin contact with benzene-containing liquids in a workplace setting does not constitute a "research" study as reviewed by an institutional human subjects protection committee. The two human *in vivo* dermal absorption studies support a flux for pure benzene of 0.4 mg/cm^2-hr. The latter value is within the range of the estimated flux values from *in vitro* studies with human skin, and relying on the 0.4 mg/cm^2-hr flux is conservative in that it is at the approximate 10th percentile of the *in vitro* study range.

When the liquid at issue is not pure benzene but an organic solvent or solvent mixture containing benzene, the accepted procedure is to reduce the flux for pure benzene by the fraction of benzene in the solvent:

Eq. (2)   Dermally Absorbed Mass (mg) =

(Flux Pure Benzene, mg/cm^2-hr) × (Fraction in Solvent) × (SA, cm^2) × (T, hr)

The validity of this procedure can be evaluated by examining two *in vitro* human skin studies which measured dermal absorption of benzene from gasoline (Adami, et al., Toxicology In Vitro, Volume 20, pages 1321-1330, 2006; Blank & McAuliffe, Journal of Investigative Dermatology, Volume 85, pages 522-526, 1985).

The Adami, et al., study used three different gasolines with benzene percent mass (weight) fractions of, respectively, 0.39%, 0.74% and 1.06% (mean value of 0.73%). The authors reported the benzene flux values through the skin but did not adjust for the actual benzene content in the gasolines; the unadjusted flux values ranged from 0.00147 to 0.00271 mg/cm^2-hr (mean value of 0.002 mg/cm^2-hr). When these flux values were adjusted by the respective mass fractions of benzene, the extrapolated flux rates for pure benzene were 0.14 to 0.46 mg/cm^2-hr with a mean of 0.32 mg/cm^2-hr (Nies and Korinth, 2008). The latter value is within the previously cited range for pure benzene observed in the *in vitro* human skin experiments, and is 0.8-fold the *in vivo* flux estimate of 0.4 mg/cm^2-hr.

The Blank & McAuliffe study used a gasoline containing 5% by volume benzene, and reported the permeability constant k_p (cm/hr) for benzene in gasoline to be 0.0014 cm/hr. The corresponding benzene flux (mg/cm^2-hr) is the product of k_p and the mass-by-volume benzene concentration C (mg/cm^3) in gasoline, or Flux = k_p × C. A 5% by volume benzene content is approximately equal to 44 mg/cm^3 (or 0.05 × 879 mg benzene per cm^3). Thus, the flux for benzene in the study gasoline was approximately 0.062 mg/cm^2-hr, or (0.0014 cm/hr) × (44 mg/cm^3). When this flux is adjusted by the mass fraction of benzene in the gasoline (approximately 0.059 wt/wt), the extrapolated flux for pure benzene is 1.05 mg/cm^2-hr. The latter value is within the previously cited range for pure benzene observed in the *in vitro* human skin experiments, and exceeds by 2.6-fold the *in vivo* flux rate estimate of 0.4 mg/cm^2-hr.

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The findings of Adami, et al., and Blank & McAuliffe signify that for benzene absorption from gasoline through human skin, it is valid to linearly extrapolate from the flux for pure benzene according to the benzene mass fraction (wt/wt) in gasoline. Consistent with this conclusion, Nies and Korinth (2008) stated that "a linear dose-absorption relationship for benzene is supported as a default assumption."

An *in vivo* study with rhesus monkeys found that benzene permeated at a 5.3-fold greater rate through damaged skin as compared to healthy intact skin (Maibach and Anjo, Archives of Environmental Health, Volume 36, pages 256-260, 1981). Damage was simulated by using cellophane tape to strip off the dead layer of cells (the stratum corneum) from the skin surface; the viable epidermis and dermis were not removed, and the investigators did not report cracks, fissures or damage in these latter tissues. There has not been a similar benzene absorption study using live human subjects with skin damage, but it is accepted that a 5-fold increase due to skin damage should be presumed when estimating benzene dermal absorption.

For example, Nies and Korinth (2008) stated that "in workers with lesioned skin, a flux of 2 mg $cm^{-2} h^{-1}$ should not underestimate the percutaneous uptake." This flux corresponds to applying the 5-fold factor due to skin damage to the 0.4 mg/cm^2-hr flux rate for healthy skin. In discussing the dermal absorption of benzene from gasoline among automobile mechanics, the authors (J. Sahmel and M. Boeniger) of Appendix II, Dermal Exposure Assessments, *A Strategy for Assessing and Managing Occupational Exposures, Third Edition* (AIHA Press, 2006, page 323), stated: " ... it was noted that absorption was increased through damaged skin by about 5-fold, which is likely to be the case among these workers". In the preamble to its 1987 benzene standard, 29 CFR 1910.1028, federal OSHA stated the following regarding benzene dermal uptake among tire builders whose hands were exposed to rubber solvent containing 0.5% benzene:

> "Workers building tires are known to have cracked and fissured skin on their hands as a result of daily contact with tire building solvents. Thus, the evaluation of benzene absorption through skin that is not intact may have a bearing on the actual benzene skin penetration of workers building tires. In this regard, the study by Maibach (Ex. No. 143-2b) indicated that benzene exposure to stripped skin in the rhesus monkey results in 5.3 times the absorption as compared to exposure to intact skin. If this factor is applied to the study results of NIOSH, approximately 32 mg (6 mg × 5.3) of benzene could be absorbed daily through skin as a result of exposure to petroleum naphtha in tire building operations ... Thus, OSHA is of the opinion that benzene absorption through the skin as a result of benzene contamination in rubber solvents is a major route of exposure in tire building operations."

I use the estimated flux of 0.4 mg/cm^2-hr for pure benzene through healthy human skin, reduced this flux according to the mass fraction of benzene in the solvent (assumed equal to 0.0039 to 0.0074), and increased the mass-fraction-adjusted flux by 5-fold to account for the damaged skin on Mr. Brown's left hand. I assume that the surface area of Mr. Brown's hand was 420 cm^2 (U.S. EPA Exposure Factors Handbook, 1997, pages 6-14). For 6 hours of skin contact with solvent during the paraffin cutting out of a 12-hour shift, I estimate that Mr. Brown dermally absorbed between 19.7 and 31.1 mg benzene:

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Dermally Absorbed Benzene = $(0.4 \text{ mg/cm}^2\text{-hr}) \times (0.0039) \times 5 \times (420 \text{ cm}^2) \times (6 \text{ hr})$ = 19.7 mg for 0.39% wt/wt benzene

Dermally Absorbed Benzene = $(0.4 \text{ mg/cm}^2\text{-hr}) \times (0.0074) \times 5 \times (420 \text{ cm}^2) \times (6 \text{ hr})$ = 31.1 mg for 0.74% wt/wt benzene

This dermally absorbed benzene mass is converted to an equivalent 8-hr TWA inhalation concentration in ppm as follows. I assume that a worker inhales air at the rate of $1.2 \text{ m}^3\text{/hr}$, and absorbs half the benzene in the inhaled air. Thus, the benzene mass absorbed from the lungs in 8 hours due to breathing an average benzene-in-air concentration of 1 ppm (equal to 3.19 mg/m^3 at normal temperature and pressure) is: $(3.19 \text{ mg/m}^3) \times (1.2 \text{ m}^3\text{/hr}) \times (8 \text{ hr}) \times (0.5) = 15.3 \text{ mg}$. Thus, Mr. Brown's daily dermal absorption of 19.7 to 31.1 mg benzene due to 6 hours of skin contact with solvent during the paraffin cutting was equivalent to inhaling 1.29 ppm to 2.03 ppm benzene in air as an 8-hr TWA value:

$$\frac{19.7 \text{ mg}}{(15.3 \text{ mg})/(1 \text{ ppm as an 8-hr TWA})} = 1.29 \text{ ppm as an 8-hr TWA}$$

$$\frac{31.1 \text{ mg}}{(15.3 \text{ mg})/(1 \text{ ppm as an 8-hr TWA})} = 2.03 \text{ ppm as an 8-hr TWA}$$

General Acceptance of the Dermal Absorption Estimation Method: I note that the same basic expression as Equation (2) was used to estimate the dermal absorption of benzene in a peer-reviewed paper by D. Paustenbach, et al., "Reevaluation of Benzene Exposure for the Pliofilm (Rubberworker) Cohort," Journal of Toxicology and Environmental Health, Volume 36, pages 177-231, 1992 [see Equation (1) on page 193]. Because skin damage was not considered in the paper, the multiplicative factor of 5 was not included. The paper lacked an Acknowledgment section, so the funding source for the work was not identified. However, two of the paper's listed authors – W. Ollison and C. Blank – were employed or affiliated with the American Petroleum Institute (API). My understanding is that Shell Oil Company is an API member, as indicated at the following website accessed on June 11, 2009: (http://www.api.org/resources/members/index.cfm#S).

The same basic expression as Equation (2) appears in a related peer-reviewed paper by P. Williams and D. Paustenbach, "Reconstruction of Benzene Exposure for the Pliofilm Cohort (1936-1976) using Monte Carlo Techniques," Journal of Toxicology and Environmental Health, Volume 66, pages 677-781, 2003 [see Equation (3), page 709]. Because skin damage was not considered in the paper, the multiplicative factor of 5 was not included. The Acknowledgment section states: "This work was partially funded by the American Petroleum Institute (API), which is the primary trade association for the U.S. oil and natural gas industry." Again, my understanding is that Shell Oil Company is an API member.

The same basic expression as Equation (2) appears in a peer-reviewed paper by J. Kalnas and D. Teitelbaum, "Dermal Absorption of Benzene: Implications for Work Practices and Recommendations," International Journal of Occupational and Environmental Health, Volume 6,

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pages 114-121, 2000 [see Equation (2), page 118]. In this paper, the authors offered an example of estimating benzene dermal absorption among vehicle mechanics having hand contact with gasoline, and assumed a 5-fold increased rate of absorption through damaged skin surfaces.

The same basic expression as Equation (2) appears in a report issued by the U.S. Environmental Protection Agency (EPA) referenced as K.T. Hoang, "Dermal Exposure Assessment: Principles and Applications," US EPA, Office of Health and Environmental Assessment, Washington, DC, EPA/600/8-91/011B, 1992. The expression appears as Equation (4.37) in Section 4.6. titled "Estimation of Absorbed Dose". In the EPA equation, the adjusted flux term appears as the permeation coefficient for the pure chemical multiplied by the chemical's concentration in the liquid (mg/cm^3). The latter parameter accounts for the fraction of the chemical of interest (for example, benzene) in the liquid.

In summary, the Equation (2) method that I use to estimate Mr. Brown's dermally absorbed benzene dose has been used by industrial hygienists for at least the past 16 to 17 years, has been accepted as scientifically valid by the U.S. EPA, and has been accepted by the American Petroleum Institute (of which Shell Oil Company is a member, according to my understanding) through the API's funding and/or coauthorship of the Paustenbach papers. I am not aware of a single critique of the method ever appearing in the peer-reviewed industrial hygiene literature. These facts establish that my dermal dose estimation method is "generally accepted in the scientific community" and is a "standard industrial hygiene practice" among those hygienists who retrospectively estimate dermal exposure.

The only written critique that I have seen of this estimation approach comes from Mr. John Spencer, a private consultant, who wrote a report for Mr. Stan Perry in the present case and in at least one previous case. I am not aware that Mr. Spencer has ever estimated a dermally absorbed dose of benzene or any other chemical; he certainly offered no estimates in his report for the present case. It is odd that a person who has not demonstrated the ability to estimate a dermally absorbed chemical dose would be called upon to critique estimates of dermally absorbed benzene doses. It is akin to asking someone who has never swung a baseball bat to critique the hitting mechanics of Hank Aaron or Babe Ruth.

Cleaning with Solvent: The same solvent used for paraffin cutting was also used to clean paraffin-cutting equipment and hand tools, as well as the decks of boats and platforms. Mr. Brown testified that to clean the paraffin cutting equipment, the equipment was placed in a trough. He said that the trough was like "a split pipe" (page 64, Brown deposition, Volume I). The trough was long enough to accommodate the 10- to 12- foot length of the lubricator pipe, and deep enough to hold solvent to a depth of several inches (page 104, Brown deposition, Volume I, January 8,2009). He used a hand brush to clean the equipment while he stood over the trough (page 105, Brown deposition, Volume I), and said he smelled the odor of the solvent while doing the cleaning (page 106, Brown deposition, Volume I). He said it took one-half to one hour to get the equipments cleaned (page 107, Brown deposition, Volume I). He did this cleaning after each paraffin cutting operation because "it would just work that much better when you went to the next location to start with a -- like starting with a new set of tools: (page 105, Brown deposition, Volume I). Mr. Brown said that during his work as a paraffin cutter, he typically would work on four to six wells each day, although he also said that he could spend two

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days on just one well and that the maximum number per day was six wells (pages 113-114, Volume I). I assume that he cleaned three wells a day, on average, and that he cleaned for 0.75 hour per cleaning sequence, on average, such that he cleaned equipment at the solvent trough for 2.25 hours per day (0.75 hr × 3 = 2.25 hr).

Evaporation of benzene (and other solvent components) from the trough subjected Mr. Brown to benzene-in-air exposure. To estimate benzene exposure intensity, I use a variation of the near field/far field model; the variation is that I ignore the contribution of the far field component to the benzene-in-air concentration. I consider a reasonable geometry for the trough (half of a cylinder with diameter 1 foot and length 12 feet) and for the near field air zone above the trough (a box of air 12 feet long, 3 feet high, and 1 foot in width) that contained Mr. Brown's breathing zone while working over the trough. The free surface area (FSA) of the near field zone is 90 ft^2, or: [2 × (12 ft × 3 ft)] + [2 × (1 ft × 3 ft)] + [(12 ft × 1 ft)]. I assume random air speeds at the boundary of the near field zone that correspond to an adjusted value of the average monthly wind speeds as reported for Venice, LA, at the following website, accessed June 12, 2009: http://www.myforecast.com/bin/climate.m?city=K7R1&metric=false. The air speed adjustment involves two factors. Because wind speed is variable, I assume that wind speeds are lognormally distributed with a geometric standard deviation (GSD) of 2. Given a fixed pollutant emission rate and air speeds that are lognormally distributed with GSD = 2, the average pollutant concentration in the near field corresponds to an air speed that is 0.62-times the mean air speed. In addition, reported wind speeds are typically measured at approximately 30 feet above the ground surface, but the wind speed decreases toward zero as the height above the ground surface decreases. Therefore, I further reduced the reported mean speed by 0.5 to account for the lower air speed on the boat deck. For each monthly average air speed value, the local dilution air flowrate β (m^3/min) into and out of the near field zone is computed by the expression:

Eq. (3) $\qquad$ β = ½ × (FSA) × (0.5 × 0.62 × mean air speed)

Again, in this scenario, FSA = 90 ft^2. I assume that "several inches" of solvent in the trough corresponded to three inches of solvent. In turn, the surface area of solvent in the trough open to the atmosphere was 10.4 ft^2 (0.967 m^2).

To estimate the benzene mass emission rate from the solvent surface G (mg/min), I used a U.S. EPA algorithm (A. Hummel, et al., American Industrial Hygiene Association Journal, Volume 57, pages 519-525, 1996) and adjusted by the fraction of benzene in the solvent:

Eq. (4) $\qquad$ $G, \text{mg/min} = \dfrac{165.6 \times MW^{0.833} \times P_v \left(.0345 + \dfrac{1}{MW}\right)^{0.25} \times A}{T^{.05}} \sqrt{\dfrac{U}{L \times P_{atm}}} \times f$

where: P_v = vapor pressure of benzene in Pascal (Pa)
$\qquad$ MW = molecular weight of benzene (equal to 78.1 g/mole)
$\qquad\quad$ T = solvent temperature in Kelvin units (equal to °C + 293.15
$\qquad\quad$ U = air speed over the liquid pool (m/sec)
$\qquad$ P_{atm} = atmospheric pressure (equal to 101,325 Pa)

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A = surface area of solvent (equal to 0.967 m^2)
L = characteristic length of the surface (equal to 1.96 m)
f = 0.0039 for Shell Tolu-Sol 5 and 0.0074 for Shell Sol B

Because benzene's vapor pressure and emission rate depend on ambient temperature, I used the average monthly temperatures reported for Venice, LA, on the following website, accessed June 12,2009: http://www.myforecast.com/bin/climate.m?city=K7R1&metric=false. For each monthly average temperature, I computed a G value based on Equation (4) . For each monthly average wind speed, I computed a β value based on Equation (3). For each month, I used these estimates of G and β to estimate of Mr. Brown's benzene-in-air exposure level while working over the trough by the expression:

$$\text{Eq. (5)} \qquad C_{NF}^* \text{ in ppm} = \frac{G \text{ mg/min}}{\beta \text{ m}^3/\text{min}} \times \frac{0.313 \text{ ppm}}{\text{mg/m}^3}$$

The asterisk on the term C_{NF}^* denotes that the far field contribution is not included. In this outdoor scenario, I judge that the far field contribution was negligible. The conversion term in Equation (5) expresses the mg/m^3 concentration as ppm at normal temperature and pressure.

For a benzene-in-solvent fraction of 0.0039, the twelve C_{NF}^* values (one for each month) range from 0.13 ppm to 0.4 ppm, with an overall mean value of 0.25 ppm. For a benzene-in-solvent fraction of 0.0074, the twelve C_{NF}^* values (one for each month) range from 0.25 ppm to 0.76 ppm, with an overall mean value of 0.48 ppm.

Equation (4) assumes a constant benzene concentration in the solvent, although the concentration likely decreased over time as the benzene evaporated. However, I judge that the benzene loss negligibly affected the benzene concentration in the solvent (by no more than 1.1%). To explain, given a solvent depth of three inches, the trough contained approximately 1.84 m^3 of solvent. The liquid density of the Shell Sol B and Shell Tolu-Sol 5 solvents were, respectively, 677 mg/mL and 702 mg/mL. Thus, for 1.84 m^3 of Shell Sol B in the trough, the initial benzene mass was 9.22×10^6 mg, or: $(1.84 \times 10^6 \text{ mL}) \times (677 \text{ mg/mL}) \times 0.0074 = 9.22 \times 10^6$ mg. For 1.84 m^3 of Tolu-Sol 5 in the trough, the initial benzene mass was 5.04×10^6 mg, or: $(1.84 \times 10^6 \text{ mL}) \times (702 \text{ mg/mL}) \times 0.0039 = 5.04 \times 10^6$ mg. For Shell Sol B in the trough, the highest estimated mass of benzene mass lost over 225 minutes of solvent use (for the month of August) was 74,700 mg, or: $(462 \text{ mg/min}) \times (225 \text{ min}) = 103,950$ mg. The latter represents only 1.1% of the initial benzene mass in the solvent in the trough, or: $[(1.04 \times 10^5 \text{ mg})/(9.22 \times 10^6 \text{ mg})] \times 100\% = 1.1\%$. For Shell Tolu-Sol 5 in the trough, the highest estimated benzene mass lost over 225 minutes of solvent use (for the month of August) was 54,675 mg, or: $(243 \text{ mg/min}) \times (225 \text{ min}) = 54,675$ mg. The latter represents only 1.1% of the initial benzene mass in the solvent in the trough, or: $[(5.47 \times 10^4 \text{ mg})/(5.04 \times 10^6 \text{ mg})] \times 100\% = 1.1\%$.

Mr. Brown likely had substantial dermal contact with the solvent during his manual cleaning of the paraffin cutting equipment. However, Mr. Brown did not offer details of his dermal contact to permit an estimate of the dermally absorbed benzene dose based on his testimony per se. At the same time, I offer a preliminary estimate based on the reasonable assumptions that the palm-

side surfaces of both his hands were continually wetted with solvent from the trough for one-half the time he spent cleaning, or: 0.5×2.25 hr = 1.125 hr. I assume that only the skin on Mr. Brown's left hand was damaged, because I have no information concerning skin damage on his right hand. Thus, I use a multiplicative factor of 2.5 instead of 5 to account for skin damage to one-half the wetted skin surface area. Based on the Equation (2) method, I estimate that Mr. Brown dermally absorbed 1.8 mg to 3.5 mg per day, on average, due to this equipment cleaning task on the days he cut paraffin.

Dermally Absorbed Benzene = $(0.4 \text{ mg/cm}^2\text{-hr}) \times (0.0039) \times 2.5 \times (420 \text{ cm}^2) \times (1.125 \text{ hr}) = 1.8$ mg
for 0.39% wt/wt benzene

Dermally Absorbed Benzene = $(0.4 \text{ mg/cm}^2\text{-hr}) \times (0.0074) \times 2.5 \times (420 \text{ cm}^2) \times (1.125 \text{ hr}) = 3.5$ mg
for 0.74% wt/wt benzene

These dermally absorbed masses would have essentially no effect on the mass emission rate of benzene from the solvent. The 1.8 mg to 3.5 mg dermally absorbed benzene is equivalent to inhaling, respectively, 0.12 ppm to 0.23 ppm benzene-in-air as 8-hr TWA values:

$$\frac{1.8 \text{ mg}}{(15.3 \text{ mg})/(1 \text{ ppm as an 8 - hr TWA})} = 0.12 \text{ ppm as an 8-hr TWA}$$

$$\frac{3.5 \text{ mg}}{(15.3 \text{ mg})/(1 \text{ ppm as an 8 - hr TWA})} = 0.23 \text{ ppm as an 8-hr TWA}$$

The equivalent inhalation exposures due to paraffin cutting and equipment cleaning, and the benzene-in-air exposure level during equipment cleaning, can be combined into an equivalent 8-hr TWA inhalation exposure level as follows.

For a 0.0039 fraction of benzene in solvent, the estimated 2.25 hr TWA benzene-in-air exposure level during equipment cleaning was 0.25 ppm. This value is equivalent to an 8-hr TWA exposure level of 0.07 ppm, or $[(2.25 \text{ hr})/(8 \text{ hr})] \times (0.25 \text{ ppm}) = 0.07$ ppm. The estimated equivalent 8-hr TWA inhalation exposures due to paraffin cutting and equipment cleaning were, respectively, 1.29 ppm and 0.12 ppm. Thus, these three values sum to an overall equivalent 8-hr TWA inhalation exposure of 1.48 ppm.

For a 0.0074 fraction of benzene in solvent, the estimated 2.25 hr TWA benzene-in-air exposure level during equipment cleaning was 0.48 ppm. This value is equivalent to an 8-hr TWA exposure level of 0.14 ppm, or $[(2.25 \text{ hr})/(8 \text{ hr})] \times (0.48 \text{ ppm}) = 0.14$ ppm. The estimated equivalent 8-hr TWA inhalation exposures due to paraffin cutting and equipment cleaning were, respectively, 2.03 ppm and 0.23 ppm. Thus, these three values sum to an overall equivalent 8-hr TWA inhalation exposure of 2.40 ppm.

I note two aspects of these estimates. First, most of the exposure is due to dermal contact with the benzene-containing solvent. Second, the estimates 1.48 ppm to 2.40 ppm exceed the current OSHA PEL for benzene of 1 ppm as an 8-hr TWA, and the current ACGIH TLV for benzene of 0.5 ppm as an 8-hr TWA. The fact that dermal absorption of benzene can lead to doses

exceeding the inhaled doses corresponding to 8-hr TWA benzene-in-air values of 0.5 or 1 ppm was recognized in a commentary by Dr. P.J. Boorgaard, Senior Toxicologist, Shell Health, Shell International, BV, The Netherlands, that was published in Human and Experimental Toxicology, Volume 27, pages 267-268, 2008. Dr. Boogaard wrote as follows:

> "In fact, the thought that dermal exposure to benzene was negligible goes back to some old papers and was perhaps true in the days when the occupational exposure limit of benzene was 100 ppm. Although the absolute dose that may enter the body following dermal exposure has not changed, it becomes relatively increasingly more important with lower airborne occupational exposure limits. In fact, dermal uptake of benzene may easily equal uptake by inhalation at the current exposure limits of 0.5-1 ppm in some situations."

Mr. Brown's dermal exposure to solvent involved in his paraffin cutting work is a situation in which dermal uptake exceeds uptake by inhalation.

These estimates of Mr. Brown's overall equivalent 8-hr TWA inhalation exposure level due to paraffin cutting and cleaning the equipment are converted to a range of cumulative exposure estimates in ppm-years by considering the duration of performing these tasks. At the upper end of the range, Mr. Brown may have cut paraffin for two years (for 26 weeks/year, 7 days/week), and his typical 8-hr TWA exposure level was 2.40 ppm. These values produce 6,989 ppm-hour of cumulative benzene exposure, equal to 3.64 ppm-year:

$$(2.40 \text{ ppm}) \times (8 \text{ hour/day}) \times (7 \text{ day/week}) \times (26 \text{ week/year}) \times (2 \text{ year}) = 6,989 \text{ ppm-hour}$$

I assume a typical work year consists of working five 8-hour days per week for 48 weeks per year; the remaining four weeks correspond to vacation days, sick days and holidays. Thus, one ppm-year of occupational inhalation exposure corresponds to 1,920 ppm-hour, or: (1 ppm) × (40 hour/week) × (48 week/year) = 1,920 ppm-hour. It follows that:

$$\frac{6,989 \text{ ppm-hour}}{1,920 \text{ ppm-hr/ppm-year}} = 3.64 \text{ ppm-year}$$

At the low end of the range, Mr. Brown may have cut paraffin for 1½ years (for 26 weeks/year, 7 days/week), and his typical 8-hr TWA exposure level was 1.48 ppm. These values produce 3,232 ppm-hour of cumulative benzene exposure, equal to 1.68 ppm-year:

$$(1.48 \text{ ppm}) \times (8 \text{ hour/day}) \times (7 \text{ day/week}) \times (26 \text{ week/year}) \times (1.5 \text{ year}) = 3,232 \text{ ppm-hour}$$

$$\frac{3,232 \text{ ppm-hour}}{1,920 \text{ ppm-hr/ppm-year}} = 1.68 \text{ ppm-year}$$

APPLYING BLACK MAGIC PAINT/TAR TO PIPE SECTIONS

Mr. Brown said that one of his tasks as a maintenance man was manually applying a Black Magic paint/tar to sections of pipe (pages 46-48, Brown Deposition, Volume I). My understanding is that: (i) Mr. Brown typically applied one gallon of the material to a 10-foot section of pipe, (ii) covering the 10 feet of pipe took approximately one hour; (3) for at least two years, Mr. Brown performed this task for two hours per day almost every day, (iv) for at least years, Mr. Brown performed this task for two hours a day for two days a week, and (v) he got tar on his hands and arms every time he worked with it. According to a Shell memorandum titled "Updated List of Materials Containing ≥ 0.5% Benzene", dated March 31,1995, the Black Magic contained benzene at 1% to 3%, presumably by weight. Mr. Brown described the tar's odor as "very strong, very strong. It was stronger than solvent" (page 47, Brown Deposition, Volume I).

Evaporation of benzene from the tar on the pipe surface subjected Mr. Brown to benzene-in-air exposure. To estimate benzene exposure intensity, I use a variation of the near field/far field model; the variation is that I ignore the contribution of the far field component to the benzene-in-air concentration. I consider a 15-minute time period during which Mr. Brown would coat 2.5 feet of pipe. I assume a reasonable near field geometry of a cylinder with radius 2.5 feet (arm's length) and length 2.5 feet such that it contained the pipe section and Mr. Brown's breathing zone while coating the pipe section. The free surface area of this near field zone is 79 ft^2, or: FSA = [2 × π × 2.5 ft × 2.5 ft)] + [2 × π × (2.5 ft)^2]. The volume of the cylindrical near field zone is 1.39 m^3. For simplicity, I assume a random air speed of 189 fpm which corresponds to the adjusted value of the average of the monthly mean speeds (equal to 609 fpm) over the 12 months. I compute the dilution air flowrate into and out of the near field zone by Equation (3), such that β = 210 m^3/min.

For a 2% benzene content, the benzene mass in 0.25 gallons of tar applied in 15 minutes was 17,033 mg, or: 0.25 × (3785 mL) × (900 mg/mL) × 0.02 = 17,033 mg. A lower (1% wt/wt) or higher (3% wt/wt) benzene content would change the benzene mass proportionally. I assume a uniform tar application rate such that for 2% benzene content, the mass of benzene applied per minute, denoted I (mg/min), is 1,136 mg/min, or: (17,033 mg)/(15 min) = 1,136 mg/min. I assume that benzene evaporates with a fractional emission rate α = 0.139 min^{-1}, which is consistent with the benzene emission rate from a penetrating oil applied to metal parts (M. Nicas and J. Neuhaus, Journal of Occupational and Environmental Hygiene, Volume 5, pages 559-608, 2008). To estimate Mr. Brown's benzene-in-air exposure concentration during the tar application, I use the following equation (M Nicas, "Quantitative Surveying – Application of Mathematical Modeling to Estimate Air Contaminant Exposure," in *Modern Industrial Hygiene, Volume I, Recognition and Evaluation of Chemical Agents, Second Edition*, by Jimmy L. Perkins, ACGIH, Cincinnati, OH, 2008):

$$\text{Eq. (6)} \quad C(t), \text{mg/m}^3 = \frac{I}{\beta} \times \left[1 - \exp\left(-\frac{\beta}{V}t\right) \right] + \frac{I}{\beta - \alpha V} \times \left[\exp\left(-\frac{\beta}{V}t\right) - \exp(-\alpha t) \right]$$

where V is the near field zone air volume, and where the time value t runs from 0 to 15 minutes. Given the inputs described, the 15-min TWA benzene-in-air exposure level was 3.36 ppm. I note that the 3.36 ppm benzene-in-air exposure level applies to the entire two hours spent

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applying the tar. If there was no other benzene-in-air exposure on a day when tar was applied, the 8-hr TWA benzene-in-air exposure level was 0.84 ppm, or [(2 hr)/(8 hr)] × (3.36 ppm) = 0.84 ppm. A lower (1% wt/wt) or higher (3% wt/wt) benzene content in the Black Magic would change the 8-hr TWA benzene-in-air exposure level to, respectively, 0.42 ppm and 1.26 ppm.

These estimates of Mr. Brown's 8-hr TWA inhalation exposure level due to applying the Black Magic paint/tar are converted to a range of cumulative exposure estimates in ppm-years by considering the duration of performing this task. At the upper end of the range, Mr. Brown applied tar for 6 days/week for two years (for 26 weeks/year), and for 2 days/week for two years (for 26 weeks/year), with a typical 8-hr TWA exposure level of 1.26 ppm. I assume that almost every day means 6 out of 7 days. These values produce 4,193 ppm-hour of cumulative benzene exposure, equal to 2.18 ppm-year:

$$(1.26 \text{ ppm}) \times (8 \text{ hour/day}) \times (6 \text{ day/week}) \times (26 \text{ week/year}) \times (2 \text{ year}) = 3,145 \text{ ppm-hour}$$

$$(1.26 \text{ ppm}) \times (8 \text{ hour/day}) \times (2 \text{ day/week}) \times (26 \text{ week/year}) \times (2 \text{ year}) = 1,048 \text{ ppm-hour}$$

$$\frac{(3,145 \text{ ppm-hour} + 1,048 \text{ ppm-hour})}{1,920 \text{ ppm-hr/ppm-year}} = 2.18 \text{ ppm-year}$$

At the lower end of the range, Mr. Brown applied tar for 6 days/week for two years (for 26 weeks/year), and for 2 days/week for two years (for 26 weeks/year), with a typical 8-hr TWA exposure level of 0.42 ppm. These values produce 1,397 ppm-hour of cumulative benzene exposure, equal to 0.73 ppm-year:

$$(0.42 \text{ ppm}) \times (8 \text{ hour/day}) \times (6 \text{ day/week}) \times (26 \text{ week/year}) \times (2 \text{ year}) = 1,048 \text{ ppm-hour}$$

$$(0.42 \text{ ppm}) \times (8 \text{ hour/day}) \times (2 \text{ day/week}) \times (26 \text{ week/year}) \times (2 \text{ year}) = 349 \text{ ppm-hour}$$

$$\frac{(1,048 \text{ ppm-hour} + 349 \text{ ppm-hour})}{1,920 \text{ ppm-hr/ppm-year}} = 0.73 \text{ ppm-year}$$

If the cumulative benzene exposure estimates due to just two processes are considered – (i) paraffin cutting/equipment cleaning, and (ii) applying Black Magic paint/tar to pipe – Mr. Brown's estimated cumulative benzene exposure ranges from 5.82 ppm-year at the high end (3.64 ppm-year due to paraffin cutting/equipment cleaning + 2.18 ppm-year due to applying tar) to 2.41 ppm-year at the low end (1.68 ppm-year due to paraffin cutting/equipment cleaning + 0.73 ppm-year due to applying tar). However, it is certain that Mr. Brown experienced additional benzene exposures as a laborer/maintenance man and as a lease operator.

EXPOSURE TO NATURAL GAS CONDENSATE

As a lease operator, Mr. Brown checked the gas flow charts on 30 to 50 wells per day (page 51, Brown deposition, Volume II). To do each chart check, Mr. Brown opened a valve and bled off

approximately one cup of a liquid condensate through a manifold valve. The manifold was "chin high" (pages 44-45, Brown deposition, Volume II), and my understanding is that Mr. Brown's breathing zone was within one foot of the manifold valve. My understanding is that the condensate was in a small bellows having the approximate size of two softballs. The condensate ran down onto the grating and into the sea. The bleed-off took approximately 5 to 10 seconds, and the entire procedure of checking the meter took about 5 minutes. Mr. Brown said there was always a strong distinctive odor associated with the bleed off procedure.

I understand that information on the benzene content of natural gas condensate from Blocks 24, 26, 27 and 28 has not yet been provided by Shell. However, benzene analyses of condensate are available from several gas plants in Shell's Southern E&P (Exploration and Production) Region, which included the offshore areas near where Mr. Brown worked. A memo dated July 3, 1978 from Carolyn Phillips, a Shell industrial hygienist, lists the benzene content of some bulk samples of condensate. A condensate bulk sample from a storage tank at the Chalkley Gas Plant had 18,000 ppm (1.8%) benzene (SHELL-BBROWN-000151). A condensate bulk sample from the Stingray Gas Plant had 11,000 ppm (1.1%) benzene (SHELL-BBROWN-000153). A condensate bulk sample from a tank at the Kings Bayou Field had 22,000 ppm (2.2%) benzene (SHELL-BBROWN-000154). I note that a Shell material safety data sheet for "stabilized natural gas condensate" (SHELL-BBROWN-238443) indicates that the benzene content of natural gas condensate could be close to 20%.

Bleeding off the liquid condensate also released gas and benzene vapor in the bellows into Mr. Brown's breathing zone. To estimate benzene exposure intensity, I use a variation of the near field/far field model; the variation is that I ignore the contribution of the far field component to the benzene-in-air concentration. I consider a 7.5-second period, which is the midpoint of the bleed-off time range offered by Mr. Brown. I assume a reasonable near field geometry of a hemisphere with radius 1 foot from the manifold valve such that it contained Mr. Brown's breathing zone. The free surface area of this near field zone is 6.28 ft^2, or: FSA = [2 × π × (2.5 ft)^2]. The volume of the cylindrical near field zone is 0.0593 m^3. For simplicity, I assume a random air speed of 95 fpm which corresponds to the adjusted value of the average of the monthly mean speeds (equal to 609 fpm) over the 12 months. For this adjustment, I further reduce the reported mean speed by one-half, because I assume that the chart box acted as a wind break. Substituting 0.25 for 0.5 in Equation (3), I estimate the dilution air flowrate into and out of the near field zone as β = 8.4 m^3/min.

The circumference of a softball is approximately 30 cm, so its radius is 4.77 cm and its volume is 456 cm^3. Thus, the approximate bellows volume (equal to two softballs) is 912 cm^3. The volume of the one cup of liquid condensate in the bellows is 237 cm^3. The difference 675 cm^3 (or: 912 cm^3 − 237 cm^3) is the gas/vapor volume in the bellows. I assume the mean temperature was 20.2° C, which corresponds to a vapor pressure of 78 mm Hg for pure benzene. I assume the benzene vapor pressure in the bellows headspace was 78 mm Hg multiplied by the fraction of benzene in the liquid. I consider that the benzene fraction could vary from 0.01 to 0.19 (1% to 19%), so the benzene vapor pressure in the headspace was 0.78 mm Hg to 14.8 mm Hg. These vapor pressure values correspond to benzene headspace concentrations of, respectively 3,278 mg/m^3 and 62,204 mg/m^3. The uniform release over 7.5 seconds (0.125 minutes) of 675 cm^3 (or 0.000675 m^3) of headspace gas/vapor containing these benzene concentrations into the near field

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zone corresponds to benzene emission rates of, respectively, 17.7 mg/min and 339 mg/min. As computed by Equation (5), I estimate that Mr. Brown's benzene-in-air exposure levels over the 7.5-second interval could range from 0.66 ppm to 12.6 ppm:

$$C_{NF}^* = \frac{17.7 \text{ mg/min}}{8.4 \text{ m}^3/\text{min}} \times \frac{0.313 \text{ ppm}}{\text{mg/m}^3} = 0.66 \text{ ppm}$$

$$C_{NF}^* = \frac{339 \text{ mg/min}}{8.4 \text{ m}^3/\text{min}} \times \frac{0.313 \text{ ppm}}{\text{mg/m}^3} = 12.6 \text{ ppm}$$

If the bleed-off took only 5 seconds, the range of exposure intensity would be 1.5-fold higher, or 0.99 ppm to 18.9 ppm. If the bleed-off took 10 seconds, the range of exposure intensity would be 0.75-fold lower, or 0.5 ppm to 9.45 ppm.

OTHER TASKS INVOLVING EXPOSURE TO BENZENE

There are other tasks Mr. Brown performed that are certain to have caused additional benzene exposure, but for which I presently lack sufficient information to quantify exposure.

Bleeding Compressed Natural Gas Lines: Mr. Brown briefly described having to bleed gas flow lines that were under 1440 pounds per square inch of pressure (pages 58-60, Brown deposition, Volume II). He said that if the line was two-inch diameter pipe, it could be bled off in one-half hour. He remained on the well jacket during the bleed off. He described trying to distance himself from inhaling the natural gas as follows: "You smell them [the gases], but you're trying to get -- hang off the rail to where you -- you know, you try to get away from it as much as you can." He said that the wind speed had a great impact on the intensity of his exposure. He said he performed this bleed-off operation approximately once a week.

At present, I do not have sufficient details of the physical circumstances of the bleed-off operations to offer benzene exposure estimates. Some of those details include the benzene content of the compressed natural gas in the line, Mr. Brown's distance from the release point, and the mass of gas that was released. The latter mass would depend, in turn, on the length of pipe that was bled. I judge that benzene exposure during such a bleed-off procedure could be quite high. For example, a two-inch internal diameter gas line that is one-tenth of a mile long has 11.5 ft^3 of internal volume. If the gas in that volume is under 1440 psi of pressure at 20° C, it contains 19,548 moles of gas. The molecular weight of natural gas is approximately 19,000 mg per mole. If the gas contains benzene at 1% wt/wt, the gas in that volume contains 3,714,120 mg benzene, or: (19,548 mole) × (19,000 mg/mole) × (0.01) = 3,714,120 mg. Release of that benzene at a uniform rate over a 30-minute period corresponds to a benzene emission rate of 123,804 mg/min, or (3,714,120 mg)/(30 min). If Mr. Brown were within a radius of 6 feet of the emission point, and if the wind speed were 189 fpm, Mr. Brown's estimated 30-min TWA benzene-in-air exposure would be approximately 64 ppm.

Contact with Crude Oil: As a laborer/maintenance man, Mr. Brown repaired leaking crude oil flow lines at least every other day (page 33, Brown deposition, Volume I). When asked if he got

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crude oil on his body, he said: "You got it all over you" (page 35, Brown deposition, Volume I). Mr. Brown subsequently described this crude oil contact as follows: "Oil soaked, I'd say a couple of times a week for sure … your clothes would actually be ruined … When we'd get in that night, we always took off our clothes and piled them in the hall" (pages 21-22, Brown deposition, Volume II). Mr. Brown also said: "Anytime you work with pipe flow lines or whatever, you're going to get crude oil on you" (pages 38-39, Brown deposition, Volume I). Mr. Brown said that the crude oil had a "strong odor" (page 35, Brown deposition, Volume I). As a laborer/maintenance man, Mr. Brown repaired levees around burn pits once or twice a week, during which time he got crude oil on his body (pages 70-72, Brown deposition, Volume I). As a laborer/maintenance man, Mr. Brown cleaned the interiors of 25-foot tall separator tanks on production platforms by spraying high-pressure water from outside the tank onto interior tank surfaces to dislodge sludge. During this cleaning, he said he became wet with the water backspray containing crude oil, and he smelled a strong odor of crude oil "all day long" (page 76, Brown deposition, Volume I). As a lease operator, Mr. Brown changed chokes on wells on a weekly basis, and as often as three times a week (page 69, Brown deposition, Volume II). He said that changing a choke took one-half hour, that he caught much of the crude oil in a bucket, but that "you're going to get it all over your hands, and then you're going to get some on the tree, and then you've got -- you've got your tools" (page 70, Brown deposition, Volume II). In addition to this testimony. Mr. Singelstad informed me that during the years 1968-1986, Mr. Brown had hand contact with crude oil six to ten times per day. This contact was in addition to the more extensive dermal contact episodes when repairing pipe leaks, repairing levees, spraying tank interiors with high-pressure water, and changing chokes.

Mr. Brown also said he cleaned up oil spills and "platform carryovers" at least once a week for approximately five years when he worked as a laborer/maintenance man in Block 24. Given his one-week-on/one-week-off schedule, this rate sums to at least 130 oil spill cleanups (26 per yr × 5 yr). In addition, during his time as a lease operator in the period 1975 to 1986, he cleaned up oil spills at least once a month. This rate sums to 144 oil spill cleanups (1 per month × 144 months). Thus, he performed at least 274 oil spill cleanups in the years 1968 to 1986.

I note that among the records of benzene analyses in crude oil samples: (i) the benzene content of a crude oil from South Pass Block 24 was 2,524 ppm (0.25%) [SHELL-BBROWN-000227]; (ii) the benzene content of a crude oil sample from South Pass Block 27 was 3,701 ppm (0.37%) [SHELL-BBROWN-000227]; (iii) the benzene content of a crude oil sample from South Marsh Island Block 27 was 2,372 ppm (0.24%) [SHELL-BBROWN-000226]; (iv) the benzene content of a crude oil sample from South Marsh Island Block 27 was 580 ppm (0.058%) [SHELL-BBROWN-002124]; (v) the benzene content of a crude oil sample from Ship Shoal Block 28 was 5,380 ppm (0.538%) [SHELL-BBROWN-002134]; and (vi) the benzene content of a crude oil sample from Ship Shoal Blocks 28 and 32 was 5,690 ppm (0.569%) [SHELL-BBROWN-002134].

It is certain that Mr. Brown's frequent contact with crude oil containing benzene led to his frequent inhalation and dermal absorption of benzene. However, at present, I do not have sufficient details of the physical circumstances of this contact with crude oil to offer benzene exposure estimates.

Gauging Crude Oil Tanks: Mr. Brown said that as lease operator assigned to a FWKO platform, he had to gauge two crude oil tanks twice a day (page 92, Brown deposition, Volume II). He said he climbed up a tank via a ladder, opened a hatch, and dropped a gauge into the tank (page 93, Brown deposition, Volume II). He said when he opened the hatch on a tank, "naturally the fumes came out of it" (page 93, Brown deposition, Volume II). He said that gauging two tanks per day took 20 to 30 minutes per day (page 93, Brown deposition, Volume II). Mr. Brown's reference to "fumes" involves the circumstance that vapors of crude oil components, including benzene, collected in the headspace of the tank, and that opening the tank hatch permitted these vapors to escape into Mr. Brown's breathing zone.

At present, I do not have sufficient details of the physical circumstances of the gauging to offer benzene inhalation exposure estimates, but I judge that benzene exposure during gauging could be quite high. For example, if pure crude oil at 25° C contained benzene at 0.3%, the benzene concentration in the tank headspace would be approximately 375 ppm. If the crude oil contained a substantial water content, the benzene concentration in the tank headspace would be much higher, because benzene's air-to-water partition coefficient is 0.22. To explain, at equilibrium partitioning between just air and water at 25° C, the benzene concentration in air (mg/m^3) is 22% of the benzene concentration in water (mg/m^3). In contrast, at equilibrium partitioning between just air and pure crude oil containing 0.3% benzene at 25° C, the benzene mass concentration in air (corresponding to 375 ppm) is approximately 1,200 mg/m^3. The latter concentration represents approximately 0.05% of the benzene concentration in the crude oil (equal to 2.4 $\times 10^6$ mg/m^3). This is to say that benzene emission from water is 440-fold greater than from crude oil. In any event, when Mr. Brown gauged a crude oil tank, headspace air containing a high benzene vapor concentration entered his breathing zone.

Solvent Use for Cleaning: To clean boat and platform decks and crude oil spills, Mr. Brown used the same benzene-containing solvent that he used for paraffin cutting. Mr. Brown said he used the solvent to clean crude oil spillage on well jackets (page 45, Brown deposition, Volume I). He said he used the solvent to clean the deck of the paraffin-cutting barge one to four times a day (page 112, Brown deposition, Volume I). He said as a maintenance man, he repaired well jacket equipment on the barge deck two or three days a week, and afterwards cleaned the barge deck by sprayed it with solvent (pages 116-117, Brown deposition, Volume I). He also sprayed solvent to clean the barge deck at the end of the day (pages 118-119, Brown deposition, Volume I). He said this solvent clean up lasted about one hour a day, and that he smelled the solvent during the cleaning (page 118, Brown deposition, Volume I). He said that as a lease operator, he tested a separator every day; when he opened an orifice on a separator, crude oil got on the platform, and he used solvent to clean the platform (pages 41-42, Brown deposition, Volume II). He said that as a lease operator, he used solvent to clean up crude oils spills on the production platform (page 82, Brown deposition, Volume II). He said he used the solvent to clean crude oil off his skin (pages 45, 72, 77, Brown deposition, Volume I; page 72, Brown deposition, Volume II; page 42, Brown deposition. Volume III).

It is certain that Mr. Brown's frequent use of the solvent for cleaning work surfaces and his skin led to his frequent inhalation and dermal absorption of benzene. However, at present, I do not have sufficient details of the physical circumstances of this solvent use to offer benzene exposure estimates.

Use of Liquid Wrench: During the period 1968 to 1973, Mr. Brown used Liquid Wrench on a daily basis (page 87, Brown Deposition, Volume I). Mr. Brown told me that he used at least several small cans each week, and that whenever he used Liquid Wrench, he got some of the liquid on his hands. In his deposition, Mr. Brown said that the Liquid Wrench came in "a little half-gallon can or some kind of spray -- spray-on, I really can't remember" (page 88, Brown deposition Volume I). When shown a picture of a 16-ounce squirt applicator can of Liquid Wrench (Exhibit 7, Volume I), Mr. Brown said: "Yes. I've seen this -- this -- the writing, like Liquid Wrench, and the colored can" (page 88, Brown deposition Volume I). At a later point in his deposition, Mr. Brown said that the 8-ounce squirt applicator can of Liquid Wrench shown in Exhibit RSC-4 looked familiar, and that he never applied the Liquid Wrench by spraying it (page 62, Brown Deposition, Volume III). Mr. Brown was asked if he used different sized cans of Liquid Wrench or if he always used a standard size. Mr. Brown's transcript answer reads: "I can remember a standard size ... I don't know how exactly, you know, to describe it, maybe (indicating) --'" (pages 62-63, Brown Deposition, Volume III). I am not clear if the transcript means that he pointed to the squirt can shown in Exhibit RSC-4, although the three other RSC exhibits depict aerosol cans.

In a subsequent "Exhibit A Errata Sheet" that Mr. Brown signed in March 2009 to verify the accuracy of his deposition transcript, he amended his answer to the question regarding whether any of the cans depicted in Exhibits RSC-1 through RSC-4 looked familiar. According to Exhibit A, not only did the Liquid Wrench can depicted in Exhibit RSC-4 look familiar, but also "the one in the photo Reed Morgan asked me about and showed me [Exhibit 7]."

My understanding of the can labeling in Exhibits 7 and RSC-4 is that the former can (which bears a "skull-and-crossbones" image, the word "Poison", and the word "Flammable") contained Liquid Wrench formulated with a benzene-containing raffinate, whereas the latter can (which does not bear a "skull-and-crossbones" image and the words "Poison" and "Flammable", but does bear the word "Combustible"), contained Liquid Wrench not formulated with a benzene-containing raffinate. Using the benzene-containing Liquid Wrench formulation would cause Mr. Brown to absorb benzene via inhalation and dermal absorption, whereas using the non-benzene-containing Liquid Wrench formulation would not cause benzene exposure. Based on Mr. Brown' amended statement, I conclude that he used both types of Liquid Wrench formulations.

I have reviewed historical Liquid Wrench documents, and I judge that the benzene content in the raffinate (drip oil) supplied by U.S. Steel Corporation was approximately 7.5% vol/vol. Based on a 7.5% vol/vol benzene content in the drip oil, and the circumstance that drip oil constituted 88.89% vol/vol of the Liquid Wrench formulation, I estimate that the benzene concentration in the raffinate-containing Liquid Wrench formulation was 6.67% vol/vol (or 0.8889 × 7.5%).

It is certain that Mr. Brown's frequent use of Liquid Wrench containing benzene caused him to be exposed to benzene via inhalation and dermal absorption. However, at present, I do not have sufficient details of the physical circumstances of his Liquid Wrench use to offer benzene exposure estimates.

EXPOSURE MONITORING AND MEDICAL SURVEILLANCE

I saw no record that Mr. Brown was ever monitored for benzene exposure due to inhalation or dermal absorption, or that air monitoring was conducted during the tasks including, but not limited to, paraffin cutting, cleaning equipment and work surfaces with solvent, tank cleaning, tank gauging, bleeding off compressed gas, bleeding off gas condensate, Black Magic paint/tar application to pipes, repairing levees at burn pits, and cleaning up oil spills. In addition, my understanding is that Mr. Brown was not part of a Shell benzene surveillance program. In this regard, a memorandum by Carolyn Phillips, a Shell industrial hygienist, dated March 28, 1988, described the benzene content of several hundred crude oil samples, including some samples from Blocks 24 and 27 in which Mr. Brown worked. The memo stated: "These analyses indicate higher benzene content than expected. We recommend evaluation of potential exposure (inhalation/skin contact) in the handling of these oils" (SHELL-BBROWN-000220). I saw no evidence that Mr. Brown was ever included in this evaluation.

I have read this Affidavit and all of the facts set forth therein are within my personal knowledge and are true and correct.
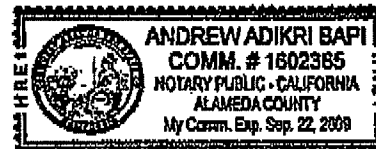
Mark Nicas, PhD, MPH, CIH

Berkeley, California

SWORN TO AND SUBSCRIBED TO before me on this the 15th day of June, 2009.

NOTARY PUBLIC AND FOR STATE OF CALIFORNIA

ANDREW ADIKRI BAPI
COMM. # 1602365
NOTARY PUBLIC · CALIFORNIA
ALAMEDA COUNTY
My Comm. Exp. Sep. 22, 2009

My commission expires: SEPT- 22ND 2009.   (SEAL)